Characteristics and hydrological effects of a cascade of benches on a semiarid hill slope in central Tunisia

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1. Abstract

The benching of hill slopes, in Tunisian semi-arid regions, is intended to reduce water runoff, soil erosion and to support infiltration on the slopes. However, the hydrologic impacts of benches remain roughly unknown. In this study, author evaluated hydrologic impact of a cascade of benches built on June 1997 on a 14.48 ha catchment area in Ousseltia region in central Tunisia. Accurate topographic measurements were used to determine precise characteristics and hydrological effects for each contour ridge. On June 2006, the total retention capacity of the cascade is roughly equal to $2535 m^3$. After nine year, the channels upstream benches have lost about 31% of their initial capacities. Each year, approximately 171 tons of sediments are retained upstream these benches. Before introducing benches, the runoff coefficient for a rainfall event of 64 mm was about 65% for uncultivated catchment area. After introducing benches, the first year, the runoff coefficient is equal to 20% for the same rainfall event. After nine years, the runoff coefficient is around 38%. Moreover, if all runoff area upstream benches have been ploughed, the runoff can be reduced to zero even after nine years. Consequently, benches considerably reduced water runoff, erosion and sediment transport on this catchment area.
Key words: semi-arid region, contour ridges, runoff, erosion, central Tunisia

2. Introduction

Actually, the anti-erosive benching is very widespread in central Tunisia. Currently, more than one million hectares of lands were arranged in benches. These soil and water conservation techniques, in semi-arid regions of Tunisia, are composed of small earth dam perpendicular to the field slope and a channel which retains surface waters and the sediments coming from area inter-benches. Usually, they are built on field slopes lower than 25% with an aim of intercepting surface water runoff, supporting infiltration and reducing erosion. Several authors described water harvesting techniques in their traditional or mechanized achievements (e.g. El Amami, 1984; Ennabli, 1993; Tobbi, 1994; Prinz, 1995, 1999). Certain studies were interested in the technical aspects of their realization (e.g. Shanan and al, 1970; Ennabli, 1993; Alaya and Al, 1993; Oweis and Prinz, 1994). Other studies described their agricultural use (e.g. Evenari and Al, 1971). A third group of studies evaluated the performances and the effects of soil and water conservation techniques on the improvement of the agricultural production and the incomes of the farmers (Oran and al, 1983; Oweis & Taîmeh, 1994). However, very few studies were interested in the quantification of their hydrological impacts (Nasri and al, 2004a, 2004b). In this paper, the author evaluated the hydrological behavior of a cascade of 14 benches and his effect on water and soil conservation on a hillside slope scale. The experimental site which was selected to study the hydrological impact of benches is a small catchment, arranged in benches during June 1997, located approximately at 15 km of Ouslatia village in central Tunisia. The benches were made in order to avoid any streaming; they are known as "benches with total retention". Figure 1 show the experimental site of 14 benches, its hydrographic network, with a linear survey of the benches, figure 2 shows an element of the benches of El Gouazine filled with water after the rain of September 24, 1998 and figure 3 shows a cross section of an element of bench. This small sub-catchment was arranged in benches on an area of 14.48 ha. The 14 benches consist of contour ridges with an average height of 1.5 m. The spacing between two successive benches varies according to the slope, between 30 to 70 m. Each element of bench has an average channel cross section of 2.28 m², thus a theoretical water retention capacity equal to $228 m^3$ for 100 linear meters.

3. Methods

A precise topographic leveling (5mx5m) was carried out using a tachometer laser in order to establish a digital elevation model (DEM) for al runoff area of the 14 benches. At the level of each element of benches, a more precise DEM (1mx2m) was carried out to deduce from them the characteristics of each element, such as the current retention capacity of its channel, the length of the bench, the direction of the flow in the channel and discharge level of the bench, as well as dimensions of the embankment. The two DEM are putted together in the same DEM which is used to define geographical dimensions of benches and to identify the water courses inside the sub-catchment area and to simulate them before the construction of the benches. The volume of the channel of each bench was calculated as being the sum of elementary volumes between the topographic profiles. The following figure n°4 represents an elementary cut of a section of bench between two successive topographic profiles.
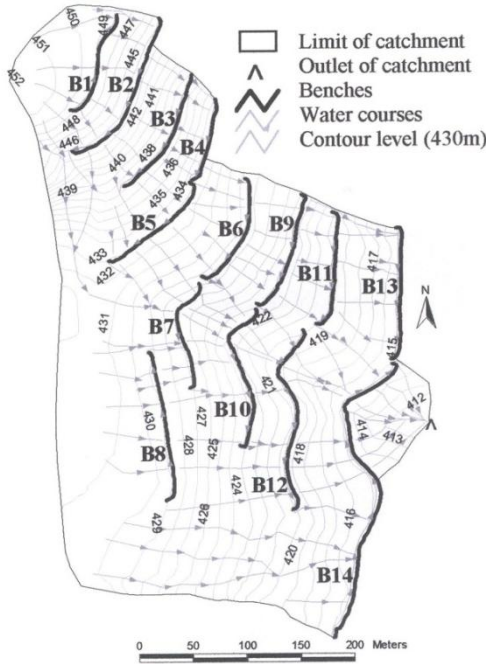
Fig.1: Experimental site of benches.

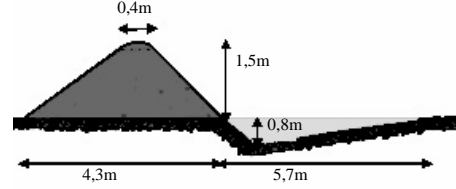**Fig. 2:** an element of bench filled with water

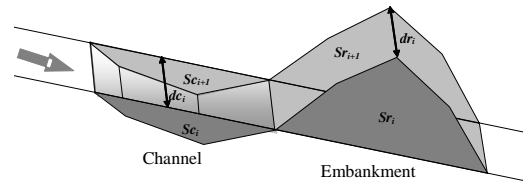**Fig. 3:** diagram of a transverse section of bench

Fig. 4: Diagram of a section of bench between two topographic profiles.

According to figure 4, the current volume of the channel can be calculated by the following formula:

$$V_{ca} = \sum_{i=1}^{i=n} \frac{(Sc_i + Sc_{i+1})}{2} dc_i \qquad [1]$$

V_{ca} : current volume of the channel of the bench, Sc_i : section of the channel of the bench at the topographic profile number i, dc_i : horizontal distance between the sections Sc_i and Sc_{i+1} of the channel of the bench and n : the total number of topographic profiles of the bench,

In the same way the current volume of the embankment of the bench can be calculated:

$$V_{ra} = \sum_{i=1}^{i=n} \frac{(Sr_i + Sr_{i+1})}{2} dr_i \qquad [2]$$

V_{ra} : current volume of the embankment of the bench, Sr_i : section of the embankment of the bench at the topographic profile number I and dr_i : horizontal distance between sections S_{r_i} and $S_{r_{i+1}}$ of the embankment.

To determine the current retention capacity of each element of bench we adopted the same method, described above, which was used to calculate the current volume of the channel of each bench. However, in this case the great base of each elementary section of the channel is materialized by the intersection of a plan corresponding to the height level of discharge of the bench with the level of the topographic profile of this section. In addition, the initial retention capacity of each bench can be calculated as being the sum of the current retention capacity with the volume of sediments retained in the bench:

$$C_{ri} = C_{ra} + V_{sed} \qquad [3]$$

C_{ri} : initial retention capacity of the bench, C_{ra} : current retention capacity of the bench and V_{sed} : volume of the sediments retained in the channel of the bench.

However, the volume of the sediments retained in the channel of the bench corresponds to the difference between current volume and initial volume of the channel:

$$V_{sed} = V_{ca} - V_{ci} \qquad [4]$$

V_{ca} : current volume of the channel and V_{ci} : initial volume of the channel,

The initial volume of the channel can be deduced from the current volume of the embankment by assumption that the product of the current volume of the embankment by the apparent density of soil which constitutes it is equal to the product of the initial volume of the channel by the apparent density of the soil of the runoff area:

$$V_{ra} d_{ra} = V_{ci} d_{sol} \qquad [5] \qquad \qquad \text{then} \quad V_{ci} = V_{ra} \frac{d_{ra}}{d_{sol}} \qquad [6]$$

d_{ra} : apparent density of the soil which constitutes the embankment and d_{sol} : apparent density of the soil of the runoff area of the bench.

4. Results

Analysis of the water courses of the sub-catchment shows that the benching modified the hydrographic network and the limits of the catchment area drained by the discharge system. The drained initial area was equal to 8.11 ha before introducing benches and it is 14.48 ha after benching. Accurate topographic measurements showed that the total areas inter-benches are about 12 ha. The surface occupied by the benches (ditch and embankment) represents approximately 17% of the total catchment area. The runoff area upstream each bench varies from 0.271 ha for the B4 bench to 3.660 ha for the B14 bench. The channels of the benches present a longitudinal slope ranging from 0 to 10‰. Each element of bench has a length varying between 83 m (B4) and 303 m (B14) and the cross section of its channel upstream varies between 0.5 to 3 m². The average runoff-area of bench is 64 m^2/ml ranging from 33 to 121 m^2/ml. The average spacing between two successive benches varies from 34 to 77 m. The current volume (in June 2006) of the channel of each bench is about 1m^3/ml. This volume varies from a bench to another from 0.42 to 1.75 m^3/ml. In addition, the surface of the channel which corresponds to the soil scraping surface to build the embankment varies from 5.6 to 10.4 m^2/ml. However, the current average depth of the channel varies from 0.23 to 0.81 m. Figure (5) shows the physical characteristics of the 14 benches.
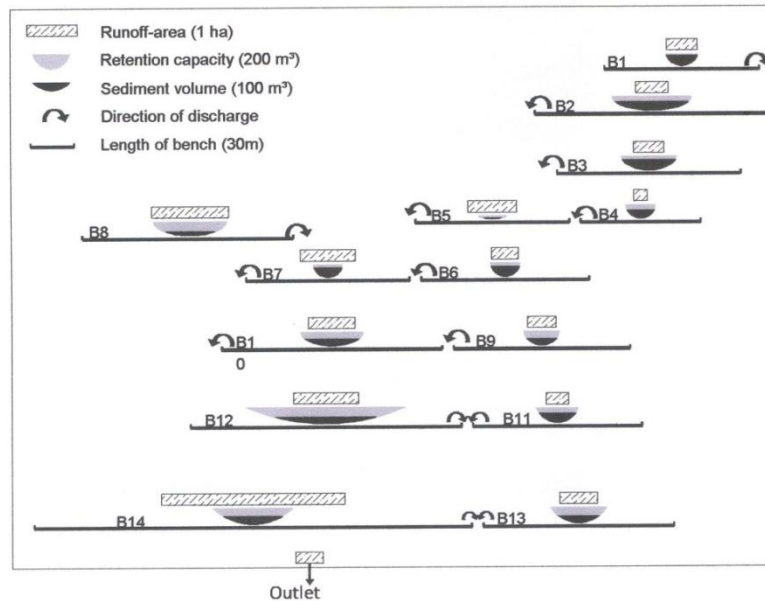

Fig. 5: Diagram of the organization in the space of the 14 benches as well as the direction of discharge of each element of bench.

The total initial retention capacity of the 14 benches is evaluated to a depth of runoff of 25 mm on all the sub-catchment. The initial capacity varies from a bench to another from 0.7 (B5) to 4.2 m^3/ml (B12). The relationship between the runoff-area and the initial capacity of each bench is very variable. This ratio varies from 17 (B2) to 125 m^2/m^3 (B5). In addition, the current total retention capacity of the 14 benches is evaluated to 17.5 mm. According to the runoff-area, we note that the current retention capacities of these benches correspond to a depth runoff varying from 3.3 (B5) to 50.3 mm (B12). After 09 years of their construction, the total present storage capacity of the 14 benches represents only 61% of their initial retention capacity. The benches B1, B7, B3 and B5 respectively lost 70%, 68%, 60% and 59% their initial capacities. Seven benches lost between 37 and 70% of their initial capacities. However, seven benches lost only 4 to 28%. The current capacity varies from a bench to another from 0.3 (B5) to 3.5 m^3/ml (B12). The ratio between runoff-area and the current capacity of each bench varies from 20 (B12) to 303 m^2/m^3 (B5).

During 09 years of existence (1997-2006), the 14 benches retain approximately 1121 m^3 of sediments. The specific erosion varies from 1.3 to 37.4 tones/ha/year with an average on all experimental area catchment of 16.9 tones/ha/year. The benches B2, B3 and B4 present values of specific erosion two to three times more important than those of the other benches. Indeed these differences can be explained by the slope which higher on the runoff-area of the benches B3 (16%) and B4 (17%). Moreover spacing of these benches (40, 51 and 36m) are relatively weaker compared to the other benches. In this case, the plow can be very closer to the channels of these benches by including a part or even the totality of the channels areas. Thus, if we don't take account these three benches, specific erosion of the experimental site will be reduced from 16.9 to 12 tones/ha/year.

Hydrological observations carried on two elements of benches just near the experimental site showed that after a rainfall-event of 64 mm provided a runoff coefficient of 65% for uncultivated runoff-area upstream the bench and 23% for a cultivated runoff-area. By using these coefficients for the 14 benches, we obtain an outflow from 12 benches out of 14 with a degraded fallow runoff-area and 04 benches out of 14 with a cultivated runoff-area.

Even on cultivated runoff-area for a rainy event of 64 mm in this cascade of benches, discharge volumes are important. They range between 45 and 96 m^3. These benches thus present a considerable risk of rupture. However, the plowing of runoff-area makes it possible to reduce by 65% the runoff volumes in the benches and by 87% discharge volumes. According to the importance of the rain, the 14 benches overflow successively in the following order: B5; B7; B1; B14; B3; B6; B9; B2; B8; B10; B13; B11; B4 and B12. We notice that the stability of this system of 14 benches depends on the stability of the benches B5, B7 and B1.

5. Conclusions

The runoff-area of El Gouazine sub-catchment was equal to 8.11 ha and become equal to 14.48 ha after its benching. This is explained by the fact that the lengths of the benches exceed the limits of the watersheds. The surface occupied by the benches is approximately 17% of the total catchment area. However, the surface occupied by benches is lost for the farmer but is can be compensated through the transformation of pasture into cultivated lands. Moreover, according to the benches the work of fields is done parallel to contour level, which increases the protection of the arable lands by avoiding the plowing in the direction of the slope. The current total retention capacity of all the benches is evaluated to approximately equivalent to a 17.5 mm depth-runoff. However, the initial capacity of these benches was evaluated to a 25 mm depth-runoff. Therefore, after 09 years of existence, this benching would have lost 31% of its initial storage capacity. This loss can be due to the silting of the channels upstream of the benches, with mechanical erosion due to the plowing of these channels. This system of 14 benches seems well to have functioned during 09 years in spite of certain heterogeneity in the storage capacities of the elements of benches. This heterogeneity however presents a risk of rupture in cascade of the benches insofar as discharges are done from one bench to another and sometimes of two benches in only one bench downstream. To improve the durability of the benching it would be desirable to homogenize the storage capacities per linear meter and to adapt these capacities to the real runoff area. Moreover, to avoid risk of discharge, it's possible to construct for each bench a weir with dry stones or cemented stones. Discharge volumes tending to grow upstream towards the downstream, it seems important to take into account the total hydrological system of a cascade of bench at the time of the design of installation. Thus, the spacing inter-benches must be calculated by taking account not only the field slope but also of the real capacities of depth runoff-area. It is also necessary to envisage discharges of benches and the organization of the cascade of benches so as to delay the flows and to avoid the excessive of discharge flows.

6. Acknowledgement

7. References

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